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SAMPLED CW MEASUREMENTS ON SINGLE CRYSTALS OF $YBa_2Cu_3O_{7-\delta}$ AND $Bi_2Sr_2CaCu_2O_8$

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ABSTRACT

Sampled Continuous Wave technique was found most suitable for investigating small single crystals of $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2CaCu_2O_8$. A unique bonding technique has been developed where the sample is pressed on to the transducer with few threads of very thin GE varnish and the transducer is mounted between parallel gold wires and a soft spring to oscillate freely. It has been found that only an optimal coupling between sample and transducer can bring out various features in the mixed phase of the of these high T_C superconducting crystals.

The results of attenuation measurements on different single crystals of $YBa_2Cu_3O_{7-\delta}$ and $Bi_2Sr_2CaCu_2O_8$ using such technique at frequencies of 3MHz and 5 MHz and in magnetic field up to 1.6T will be presented. Early work on untwinned YBCO revealed pronounced field dependent attenuation changes that were indicative of transitions from soft vortex system at low fields to a rigid vortex system at high fields. In addition, for untwinned YBCO, ultrasonic signatures of melting transition and possibly depinning transition of the flux line lattice were observed below the critical temperature.

For twinned YBCO crystal and BSCCO crystal, sharp field dependent attenuation drops were observed below the critical temperature and are easily identifiable with the normal-superconducting transition. In addition, in the superconducting mixed state there were field dependent transitions analogous to the melting transition of the flux lattice. This melting phenomenon was also investigated extensively for YBCO using ac-susceptometry technique.

TRANSCRIPT

DR. DASGUPTA: I am going to talk about some ultrasonic measurements on two high-temperature superconducting materials, YBCO and BSCCO.

[Transparency 1]

I learned quite a few things here and I heard the words "thermally activated" and a few other things that are there in this experiment. These are the people who are and were involved in these experiments -- I made the transparency, so I am on the top. (Laughter)

Jeff Feller is the person who I go to whenever I have an electronics problem. The name that is not here is somebody from whom I also learned a lot, and that is Mark McKenna. Carsten is the person this whole work started with and, of course, Moises and Bimal are always there. People, who funded this work, are the graduate school and physics department at UW-Milwaukee and ONR.

[Transparency 2]

The reason this project started was for developing an ultrasonic technique to investigate the properties of small high-temperature superconducting crystals. I think Jay Maynard was trying to show us some pictures about how small these HTS single crystals are and I can assure you they are small. Typically they are about 1000 by 800 microns and I work with crystals that are between 50 and 70 microns thick, so they are pretty small.

It is very hard to bond transducers on these small crystals and do conventional ultrasonics and, even if you can bond it, there are instrument limitations, pulse width, duty cycle, and all these things to worry about and do successful conventional ultrasonics.

[Transparency 3]

Moises and Carsten started this project to find out an alternate ultrasonic technique, and what came out is sampled CW. The outline of this presentation is: I will just quickly go through some essentials of type II superconductors, including flux lines and pinning, and then go through the description of the sampled CW and try to present the results on YBCO, untwinned and twinned crystal. If there is time left, probably I will present some susceptibility results as further verifications and also some ultrasonic results on BSCCO.

[Transparency 4]

This is a colorful but very complex diagram. This is a phase diagram of a type II superconductor. Many features are just a little enhanced for clarity. The most important part for this work is the mixed phase, where there is partial penetration of flux lines. What is in this phase, and how the flux lines behave, interact, and everything is what everybody is trying to study.

Most of the results that I will present here are mostly concentrated around this part. In the mixed phase the flux lines exist in two distinct phases. One is the flux liquid where they are entangled and the other one is a flux solid, where they are arranged in a hexagonal lattice form.

[Transparency 5]

The mixed phase is probed, in all experiments, through some sort of current. Whenever you try to send a small amount of current, you set up a force and these flux lines start moving. Essentially the motion of the flux lines results in dissipation in the sample.

Type II superconductors as such, pure type II superconductors, are not that useful because of free motion of flux lines resulting in dissipation. There can be different kinds of forces acting on the flux lines. One that plays the most important role is the Lorentz force, originating from a (transport-type) current and that results in a Lorentz force on these flux lines.

[Transparency 6]

To make these materials technologically useful, one can concentrate on are the defects, because the defects impede the motion of flux lines by pinning. There are different kinds of defects that are possible. Some are intrinsic, like oxygen vacancies between planes and some are introduced by external irradiation or other processes.

Most of the time externally-induced defects like columnar defects are far better in pinning than naturally occurring defects such as twin planes or so, but that is a totally different area of study. The important fact is that defects can stop the flux lines from moving and that reduces the dissipation.

[Transparency 7]

With this I will go into a brief description of what the CW technique is. Essentially you set up a resonance in the sample, a standing wave resonance, and one can lock into one of the resonances and change external parameters. Change in frequency typically results in change in velocity, and change in amplitude typically gives rise to attenuation. Monitoring the change of these quantities as a function of either temperature or magnetic field, one tries to extract information about the physical state.

[Transparency 8]

In Sampled CW, instead of sending a continuous wave into the sample, the RF signal is gated and is "ON" for a certain time and sets the transducer and the sample in oscillation. And then it goes "Off" and the transducer and the sample starts ringing down with a characteristic Q.

What we do in this experiment is look at the amplitude at two different times, where the gates are kept fixed, and see how it changes i.e. how the amplitude changes as we change the temperature or the magnetic field.

The sample is typically just placed on the transducer and then it is held onto the transducer with a few, typically four or five, GE varnish threads. When the threads dry and the sample is cooled down, the threads become stiffer and they just press the sample onto the transducer.

There is a model by Dr. Jeff Feller that discusses this aspect of coupling between the transducer and the sample. It is in the proceedings of the last resonance meeting. The argument is that the coupling between the sample and the transducer has to be optimal and this optimal coupling is not achieved by directly bonding the sample with the transducer. We tried Nonac, Epoxy, and we tried just GE varnish as direct bond materials. We tried different coupling schemes and the one that works best is the one with varnish threads pressing the crystal on the transducer.

The transducer rests on two copper wires and two RF spring contacts come from the top and slowly hold the whole thing down against the gold wires. When you apply the RF pulses, the whole transducer + sample system oscillates nearly freely.

The key is to oscillate the system at such a wavelength that, let's say, the ion on this face and the ion on this face of the YBCO crystal do not have a displacement gradient between them. They are moving in unison. The choice is to do an experiment with λ that is much, much greater than the thickness of the sample.

Typically, we do work with samples with a thickness of about 50 microns to 70 microns and I did some experiments with a 200 micron-thick sample and it did not give results as well as I thought. Actually, there is a lot of noise or something that is not right.

In what I called a micro-view here is an effort to explain what this whole technique is all about. Acoustically we induce motion in the bulk ionic lattice to which the flux lines are coupled. Thus, when I am moving the ionic lattice, it is not dragging the whole flux line lattice but it is just creating some local flux line density modulations leading to variations in interaction among flux lines and thus changes the nature of dissipation in the flux-lattice system.

[Transparency 9]

This is a crystal that was naturally untwinned. Naturally untwinned means the crystal has no twin boundary defects as it has grown. De-twinned is something where you physically remove the twin by applying pressure.

Anyway, so this was a naturally untwinned crystal and the only type of defect that one expects in this crystal are the oxygen vacancies. I started doing temperature sweeps instead of field sweeps because I thought field sweep is a more dynamic process. In changing the field, you are trying to push the flux lines in (or out). I wanted to keep the density of flux lines constant and, instead, vary the thermal energy and the pinning strength by changing the temperature.

What I came up with is a wonderful feature. First of all, I did get the turnaround feature of the soft-rigid transition, which was exciting. The second thing I noticed was there were some kinks in the squares.

[Transparency 10]

This is just a plot of the transitions from there and this is a plot of an empirical melting curve. The locations of the kinks are also shown here. It's apparent that the predominant transition seen here is not the melting but rather the soft rigid transition in the flux lattice system as was first seen by Hucho and Levy.

[return to Transparency 4]

The melting curve in this temperature range has a behavior like this. I said before that many features are enhanced. This gap is about 1 gauss. The gap between the H_{c1} line and the lower branch of the melting curve is about 1 gauss.

[Transparency 11]

Next, comes twinned crystal and obviously there are some features over here. A reasonable background due to the transducer and the threads has been subtracted.

There is an onset of a transition here and there is a different kind of transition here. When I plot this first onset of the transition, what I found are points like this and a fit, which coincides remarkably with dependence of H_{c2} on temperature. What is remarkable is this sample is characterized by other techniques. The T_c came out to be 93.8K. In these experiments, we sweep the temperature down or up and the thermal lag is about 0.4K.

If I add that 0.4K to this, I get the T_c back. The $H_{c2}(0)$ is 261T and essentially is the H_{c2} at zero Kelvin. That number is within ±10Tesla of many published results. That was one of the first incidents when I thought, okay, maybe I am seeing H_{c2} in all these first set of transitions.

The slope dH/dT of this curve at T_c is a little off. Here it is -5.6 Tesla/Kelvin compared the reported number of -4.2 Tesla/Kelvin. One reason for this difference might be because I am looking at a very small field range and few data points. Nevertheless, it is interestingly close.

[Transparency 12]

The next is if I plot where this attenuation is kind of getting to a minimum point. If I plot those points, I end up with a fit that goes as $(1 - t)^2$ and this is not a mean-field type temperature dependence. It is a totally different kind of temperature dependence. This is the kind of temperature dependence that the melting curve has.

The next choice was to verify all these things, doing something else. How am I doing in time?

DR. BASS: You have a couple of minutes.

DR. DASGUPTA: May I show something without submitting the transparencies? (Laughter)

[Transparency 13]

I am going to skip all those things, partly because there are some other labs and other people involved. It is not classified but maybe there are some important things involved.

The same sample was characterized using susceptibility and that is a technique where you look at magnetization and that is very useful for an effect called peak effect. Peak effect is very closely associated with melting of flux lines.

Doing susceptibility work, what we found was that there is a re-entrant behavior of this peak effect. The only reason I asked for that permission is because this is not published and other people are involved with this work. The most important thing is that right where I am finding the melting with ultrasonic technique and that's where we also see there is melting and peak effect from susceptibility. I can also find H_{c2} from susceptibility results. The temperatures and everything else just match perfectly. I have no reason to doubt the ultrasonic results on YBCO to be melting and the other one to be to onset of superconductivity.

[Transparency 14]

I will finish by showing you -- I will take just a couple of minutes -- this is for you (Moises), for a long time you kept on telling me, why don't you just put it parallel to the c-axis and do it? I did it, not for YBCO, because the crystals are in some other lab, but for a BSCCO crystal. Once again, these broad peaks are all due to thermally activated motion of flux lines.

It is there in YBCO, also, and there are some results on that. Beyond these broad peaks BSCCO has a much larger flux-liquid region than YBCO, so I am not surprised that this peak is actually a little on lower temperature side compared to YBCO before attenuation goes down.

Once again, if I plot this transition, the first thing I do is just plot it and then try to fit it. The best fit that I get, once again, is melting transition. The good thing to come out of this is a factor called c_L, which is a Lindemann factor for melting. It comes out to be 0.18. According to melting theory, it should be between 0.1 and 0.2. I am happy with the number.

The thing that does not come out right is in this fit is the reduced temperature t (T/T_c). Here it gives me a T_c of 89, but I know that this sample has a T_c of 95. I never did experiments with H parallel to the c-axis before, so I really need to repeat these experiments again and more carefully before a conclusive argument can be made.

[Transparency 15]

To conclude, yes, sampled CW can be the ultrasonic technique for looking at small high-T_c crystals until Jay comes out with his RUS or RUS-like technique. The good thing about ultrasonics, or even this technique, is that there are minimum external perturbations; I control what the induced current is going to be and I can keep it minimum. It is also possible to look at the bulk elastic properties of the flux lines. That is something I started doing recently.

DR. BASS: We have run out of time and will have to stop. Thank you.